Disturbance of Soil Organic Matter and N Dynamics: Implications for Soil and Water Quality (CS-1114D-00)

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Contents

- Background
- Project Status
- Research Summary
  - Spreadsheet models
  - Stella® models
  - Experimental disturbance at K-11
  - Spatial analysis of potential excess N
- Closeout Plan
- Research Needs
- Supplementary Slides

Background: Research Goals

- Develop a better understanding of the effects of disturbance on key measures of soil quality at Fort Benning
  - Bulk density
  - Soil carbon and nitrogen
- Determine if there are thresholds to soil quality that affect ecosystem recovery or sustainability (i.e., critical levels of soil N)
  - Process models for soil C and N
  - Predict thresholds from models

Background: Tasks and Accomplishments

- Task 1: Characterize effect of disturbances and land use on soil quality
  - Accomplishment: quantified differences in measures of soil quality across a gradient of military disturbance (published)
- Task 2: Determine disturbance thresholds to ecosystem recovery
  - Accomplishment: predicted thresholds to recovery for old fields and forests
  - Accomplishment: delineated factors that govern establishment of thresholds
- Task 3: Model soil organic matter for different land cover categories
  - Accomplishment: developed spreadsheet and Stella® models for soil C and N in old field and forest ecosystems
- Task 4: Contribute to planning of field experiments on disturbance
  - Accomplishment: currently measuring effects of K11 disturbance on soil C and N
- Task 5: Analyze spatial patterns of soil C and N, and predict nonpoint N sources
  - Status: presently exploring tools for spatial analysis of soil N availability

Background: Project Flowchart

Predict System Response to Disturbance and Identify Thresholds to Recovery

Build mathematical models:
1. spreadsheet models (simple)
2. compartment modelling (complex)

Field measurements from:
1. disturbance gradients
2. different land cover categories
3. forest chronosequences

Landscape level analysis of soil C and N dynamics (GIS data + field data + modelling)

Project Status: Presentations

- Last Year
  - Garten, C.T., Jr., and T.L. Ashwood. 2002. Disturbance of soil organic matter and nitrogen dynamics: implications for soil and water quality. Platform presentation at SEMP Research Coordination Meeting, October, Columbus, GA.
  - Garten, C.T., Jr., and T.L. Ashwood. 2002. Resource threshold modeling based on soil carbon and nitrogen dynamics at Fort Benning, GA. Poster presentation at 2002 Partners in Environmental Technology Technical Symposium and Workshop, December, Washington, DC.
- Upcoming
  - Garten, C.T., Jr. 2003. Modeling soil quality thresholds to ecosystem recovery at Fort Benning, Georgia, USA. Poster presentation at 2003 Partners in Environmental Technology Technical Symposium and Workshop, December, Washington, DC.

Project Status: SEMP Data Repository

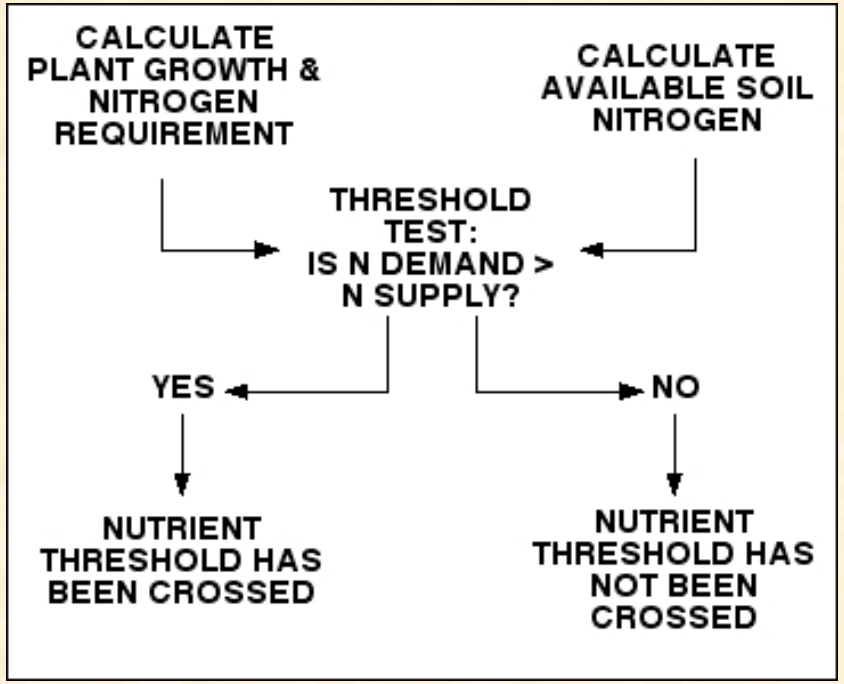
- Studies Along ORNL Team 1 Disturbance Gradient -- Soil C & N
  - Soil bulk density, soil C and N concentrations, soil C:N ratios (15 parameters)
  - Metadata file: CS-1114D-00-01Meta; Data file: CS-1114D-00-01Data
- Studies Along ORNL Team 1 Disturbance Gradient -- POM, MOM, & Refractory C
  - Data for particulate organic matter, mineral-associated organic matter, and refractory soil carbon (17 variables)
  - Metadata file: CS-1114D-00-02Meta; Data file: CS-1114D-00-02Data
  - Electronic Metafile Name: CS-1114D-00-02Meta
- ORNL Team 2 Soil Data
  - Soils data collected through 31 Dec 2003 from 129 sites (114 variables)
  - Metadata file: CS-1114D-00-03Meta; Data file: CS-1114D-00-03Data
- ORNL Team 2 Site Photos
  - On CD-ROM and ready to enter into repository

Project Status: Publications

- Garten, C.T., Jr., T.L. Ashwood, and V.H. Dale. 2003. Effect of military training on indicators of soil quality at Fort Benning, Georgia. Ecological Indicators 3: 171-179.
- Garten, C.T., Jr., and T.L. Ashwood. Land cover differences in soil carbon and nitrogen at Fort Benning, Georgia. Applied Soil Ecology (submitted and in review).
- Garten, C.T., Jr. Modeling soil quality thresholds to ecosystem recovery at Fort Benning, Georgia, USA. Journal of Applied Ecology (ready to submit).
- Garten, C.T., Jr. Identifying thresholds to ecosystem recovery with a compartment model of soil carbon and nitrogen dynamics. (planned journal article based on Stella® model).

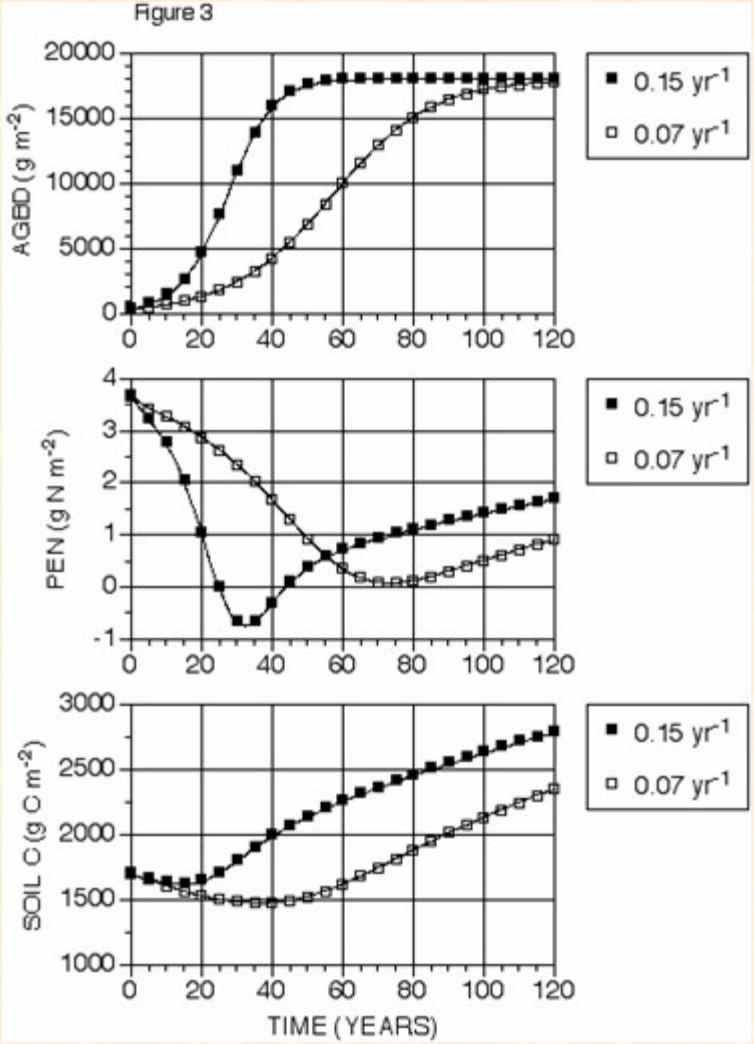
Spreadsheet Model: Concept

- Dynamic components
  - Plant biomass
  - Soil carbon
  - Soil nitrogen
  - Plant N requirement
- The model asks the question:
  - *Are soil N supplies sufficient to meet the N demands of growing biomass associated with a DFC?*
- Parameterized using both field measurements and literature data
- Simple - few parameters
- Limitation - no feedback on growth; some processes are not represented (e.g., denitrification & N_2-fixation)


CALCULATE PLANT GROWTH & NITROGEN REQUIREMENT
CALCULATE AVAILABLE SOIL NITROGEN
THRESHOLD TEST: IS N DEMAND > N SUPPLY?
YES
NO
NUTRIENT THRESHOLD HAS BEEN CROSSED
NUTRIENT THRESHOLD HAS NOT BEEN CROSSED

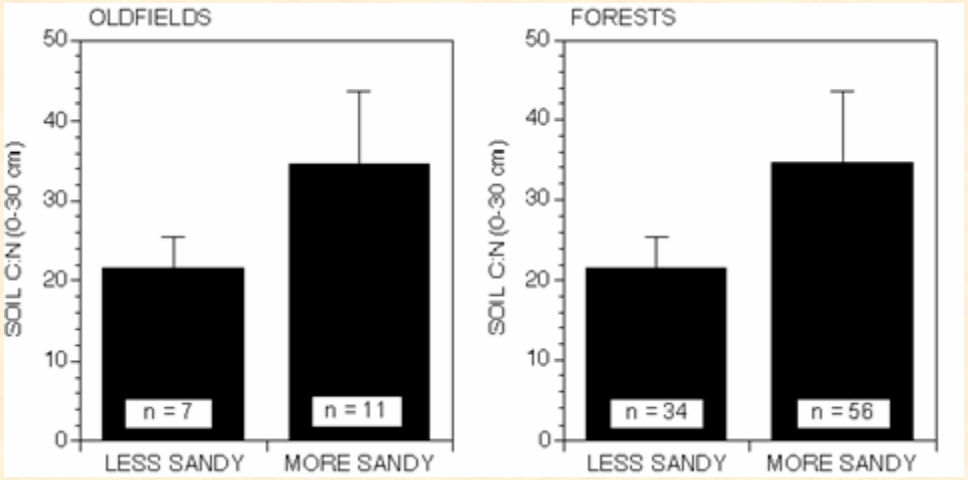
Spreadsheet Model: Example Output

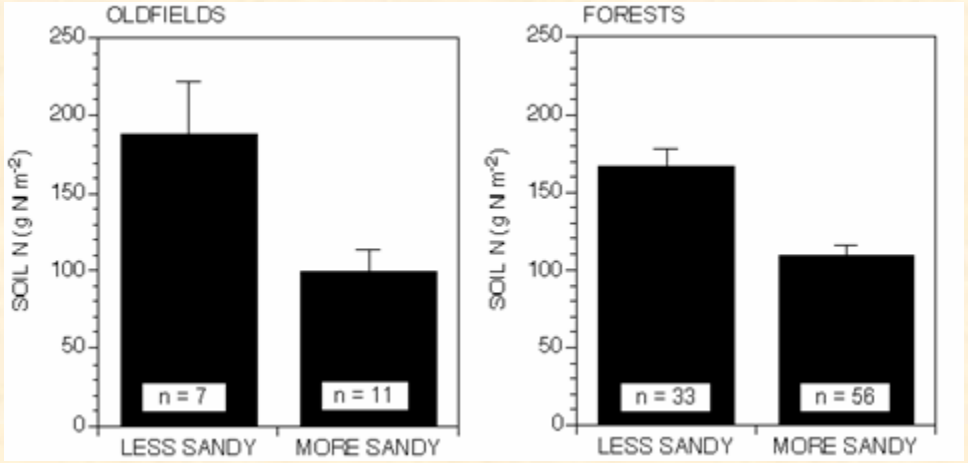
- Predicts aboveground and belowground biomass over time
- Occurrence of a threshold (negative PEN) depends on the desired future condition and the specified recovery rate
- PEN is potential excess soil N
  - Inputs (mineralization + atmospheric deposition + fertilization)
  - Outputs (plant uptake)
- Figure illustrates examples of forest recovery at two different growth rates
- Predicts recovery of soil C and N
- Internal N translocation is calculated



Spreadsheet Model: Sand & Soil Properties

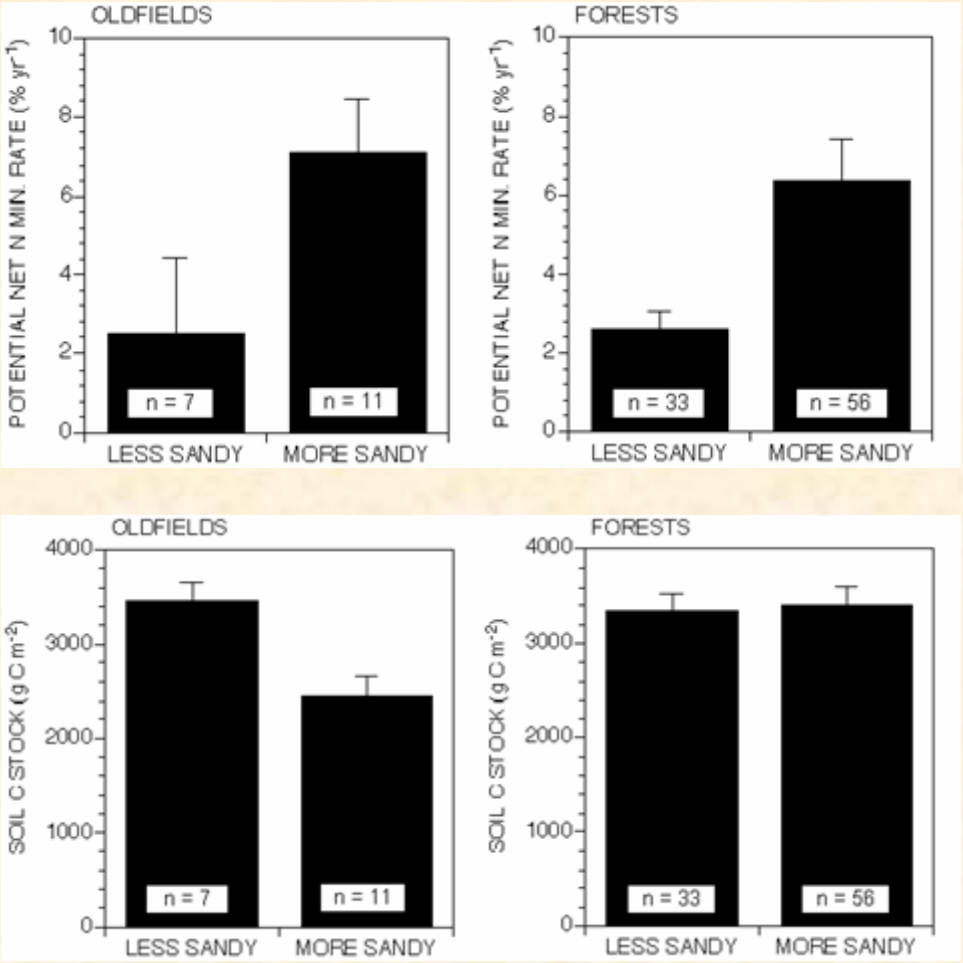
- 129 sites in the final data set
  - 109 under perennial cover
  - 20 barren sites
- Mean sand content was 70%
- Soils were binned into two categories
  - “less sandy” = sand < 70%
  - “more sandy” = sand > 70%
- Soil C:N ratios were higher and soil N stocks were less on more sandy soils in both old fields and forests





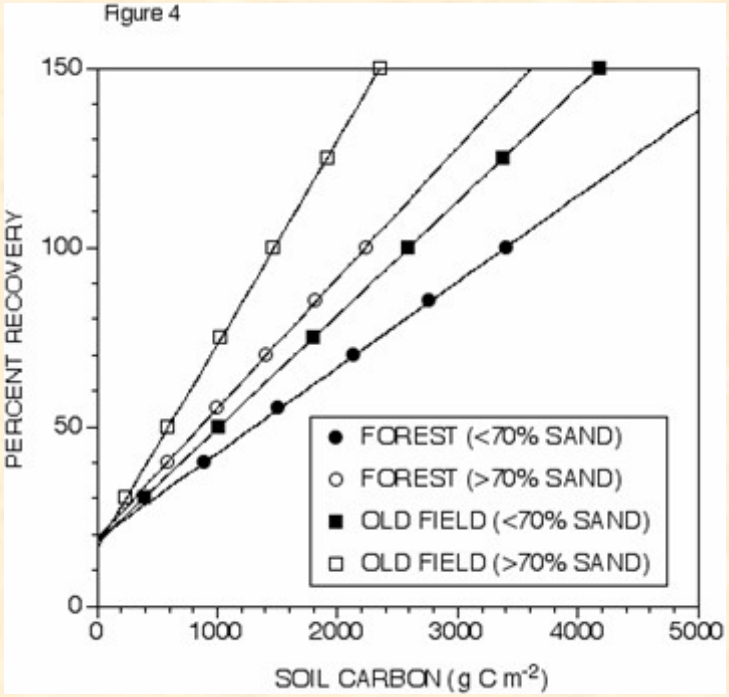
Spreadsheet Model: Sand & N Availability

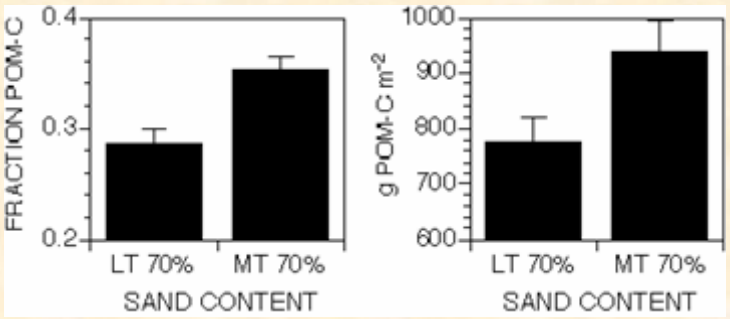
- Potential net soil N mineralization was normalized for soil N concentration and converted to an annual rate for use in the spreadsheet model
- Unexpectedly, more sandy soils had higher potential rates of net soil N mineralization
- Difference did not track trends in soil organic matter
- Differences between soil types necessitated a recalculation of thresholds to recovery based on soil sand content



Spreadsheet Model: Thresholds & Sand

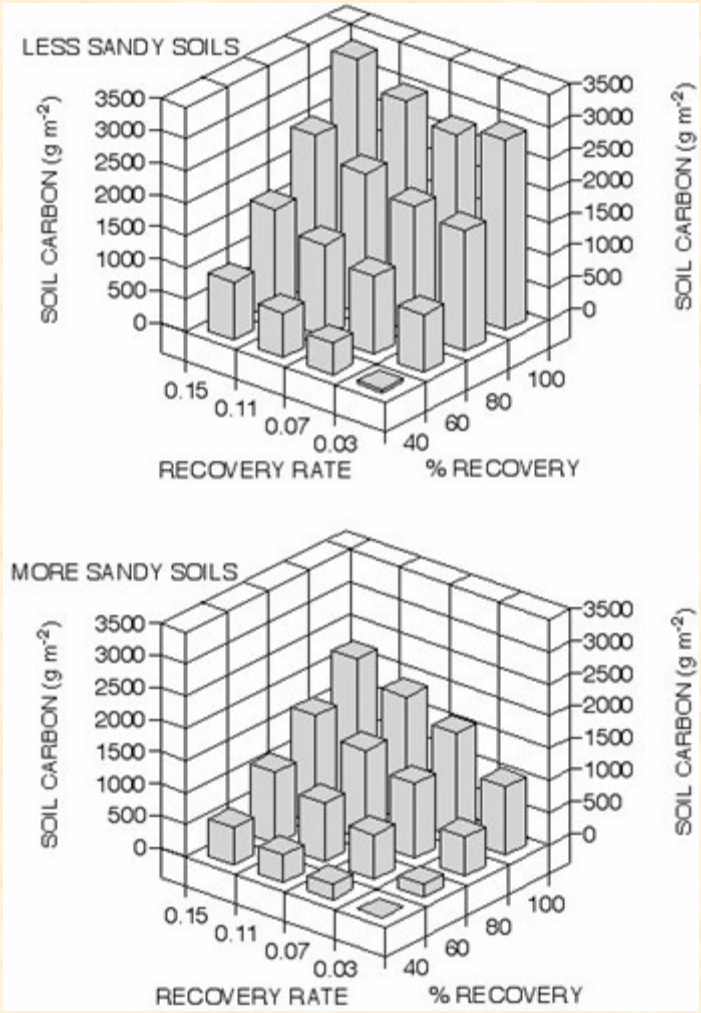
- Forests and old fields on soils with differing sand content had different predicted thresholds to recovery of a DFC
  - 100% forest recovery is predicted at approx. 2200 g C m^{-2} on more sandy soils (lower threshold)
  - 100% forest recovery is predicted at approx. 3400 g C m^{-2} on less sandy soils (higher threshold)
- More sandy soils under perennial vegetation had significantly more soil C in particulate organic matter
- *Greater amounts of labile soil organic matter in more sandy soils may contribute to higher soil N availability*



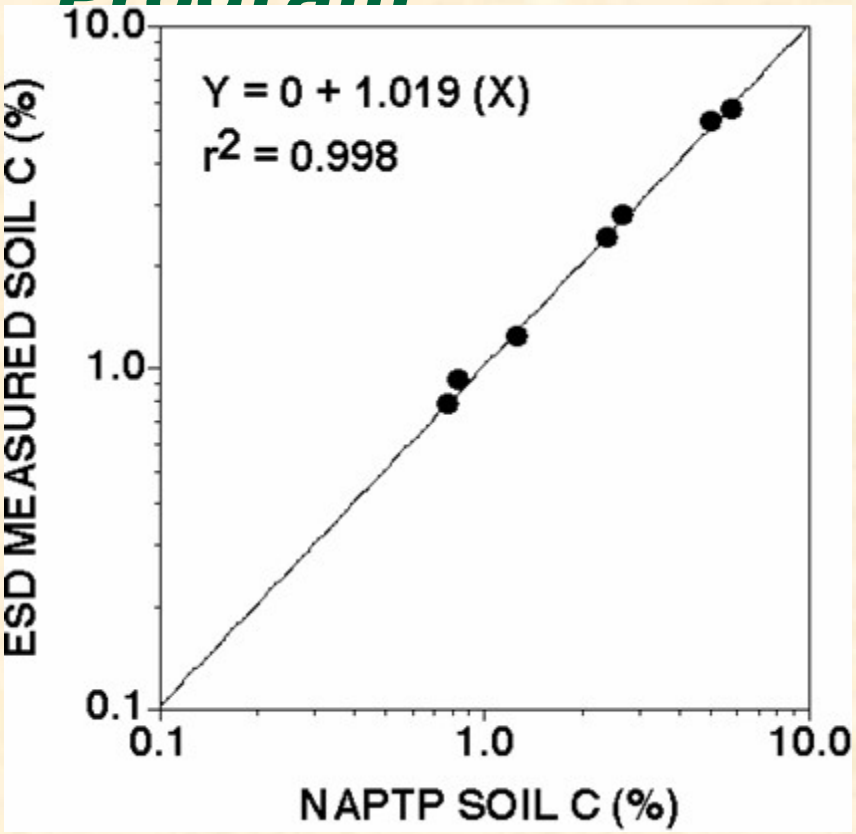


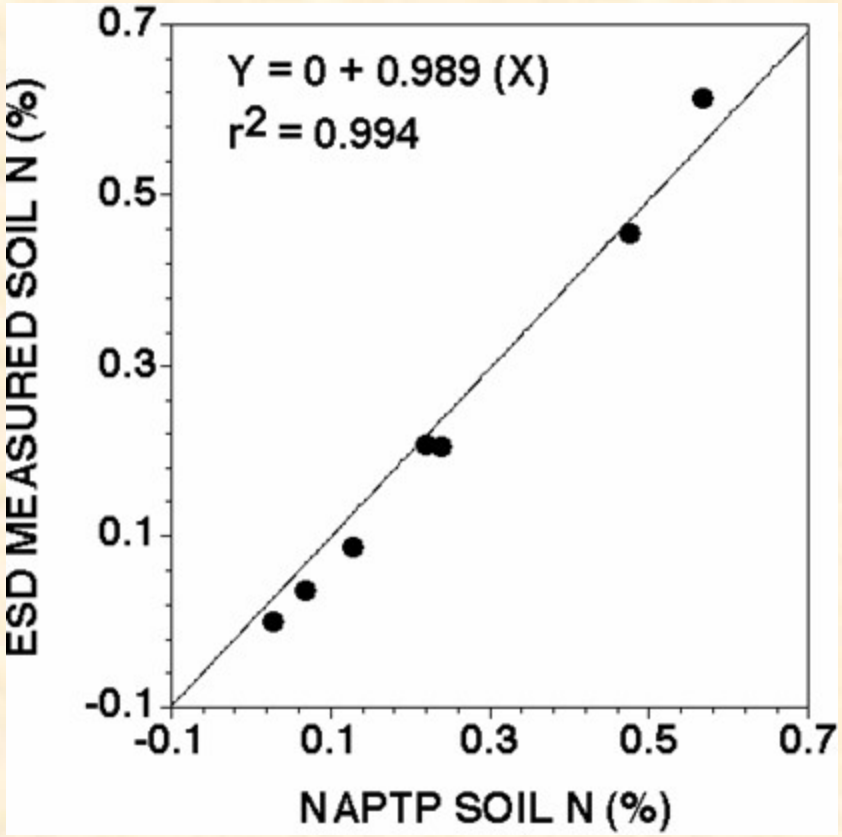
Spreadsheet Model: 3D Plots

- Effect of varying recovery rate and percent recovery to forest cover on predicted thresholds for less sandy and more sandy soils at Ft. Benning
- 100% recovery is predicted for low initial soil C stocks (1000 g C m^{-2}) on more sandy soils but only at low recovery rates
- 95% CI about mean soil C stocks on barren land at Ft. Benning was 313 to 944 g C m^{-2}
- Soil C stocks at barren sites on Ft. Benning generally lie below the predicted threshold for 100% recovery of forest cover



N. American Proficiency Testing Program





- Results for soil C determinations are excellent
- Results for soil N determinations are very good for concentrations >0.2%

Comparison of C:N Ratios

Study	Soil Depth (cm) 0	10	20	30	40	50
Binkley et al.	30 - 36	25 - 30	C:N			
Markewitz et al.	23 - 37	29 - 42	26 - 107			
Garten et al.	29 ± 1	30 ± 1	31 ± 2	27 ± 3		

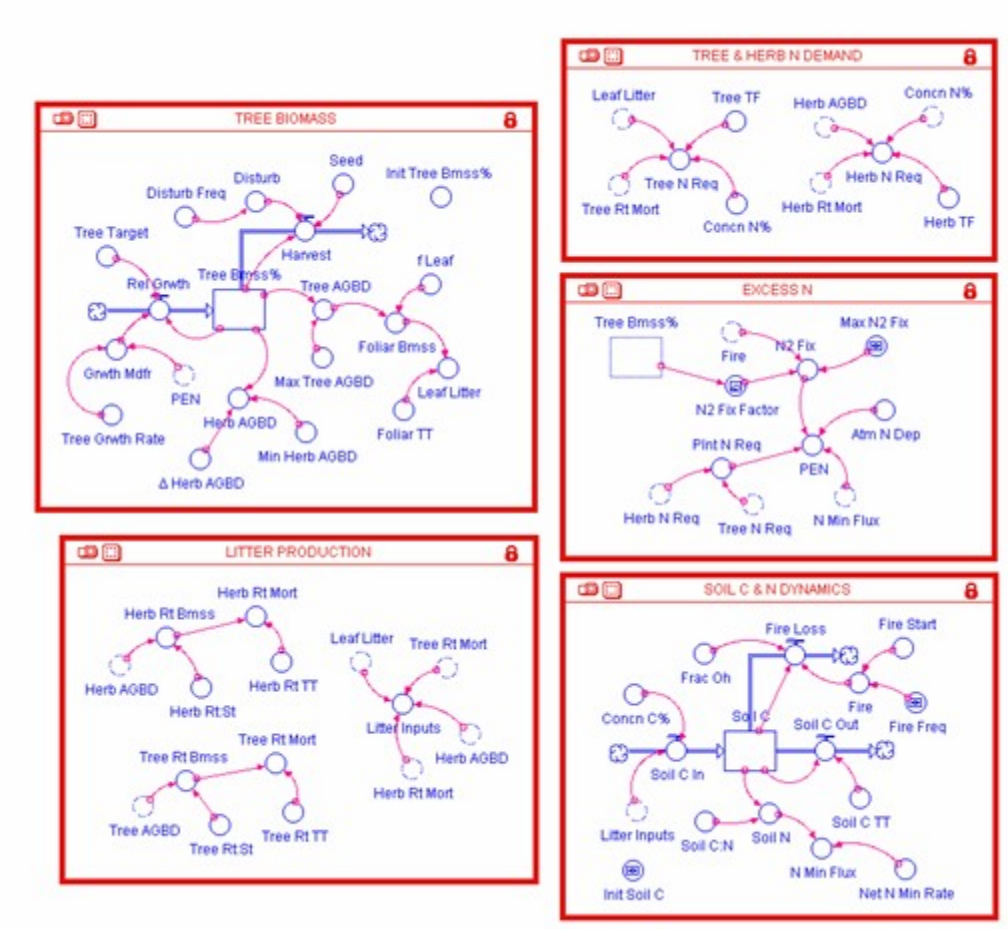
- Underestimation of soil N concentrations would tend to inflate soil C:N ratios
- Mean (±SE) soil C:N ratios in our samples from Fort Benning (n = 108) are comparable to those reported by other authors for southeastern coastal plain soils
- What other QA measures do SEMP teams have in place for the measurement of very low soil N concentrations? Can we do some inter-laboratory comparisons?

Spreadsheet Model: What Was Learned?

- Four factors were important to development of predicted thresholds to recovery
  - Initial amounts of aboveground biomass (i.e., how far is the initial state from the DFC?)
  - Initial soil C stocks (i.e., how much has the soil quality been degraded?)
  - Relative rates of biomass recovery (i.e., how fast do you want the system to recover?)
  - Soil N availability (i.e., thresholds to recovery are inversely related to soil N availability)
- Thresholds predicted by the model should not be interpreted independent of the specified rate of recovery to a desired future condition (i.e., biomass target)
- Sensitivity analysis of model parameters (in order of increasing importance): parameters related to biomass dynamics, leaf [N], N translocation, dynamics of old soil C, soil N mineralization rate, dynamics of labile soil C

Stella® Model: Concept

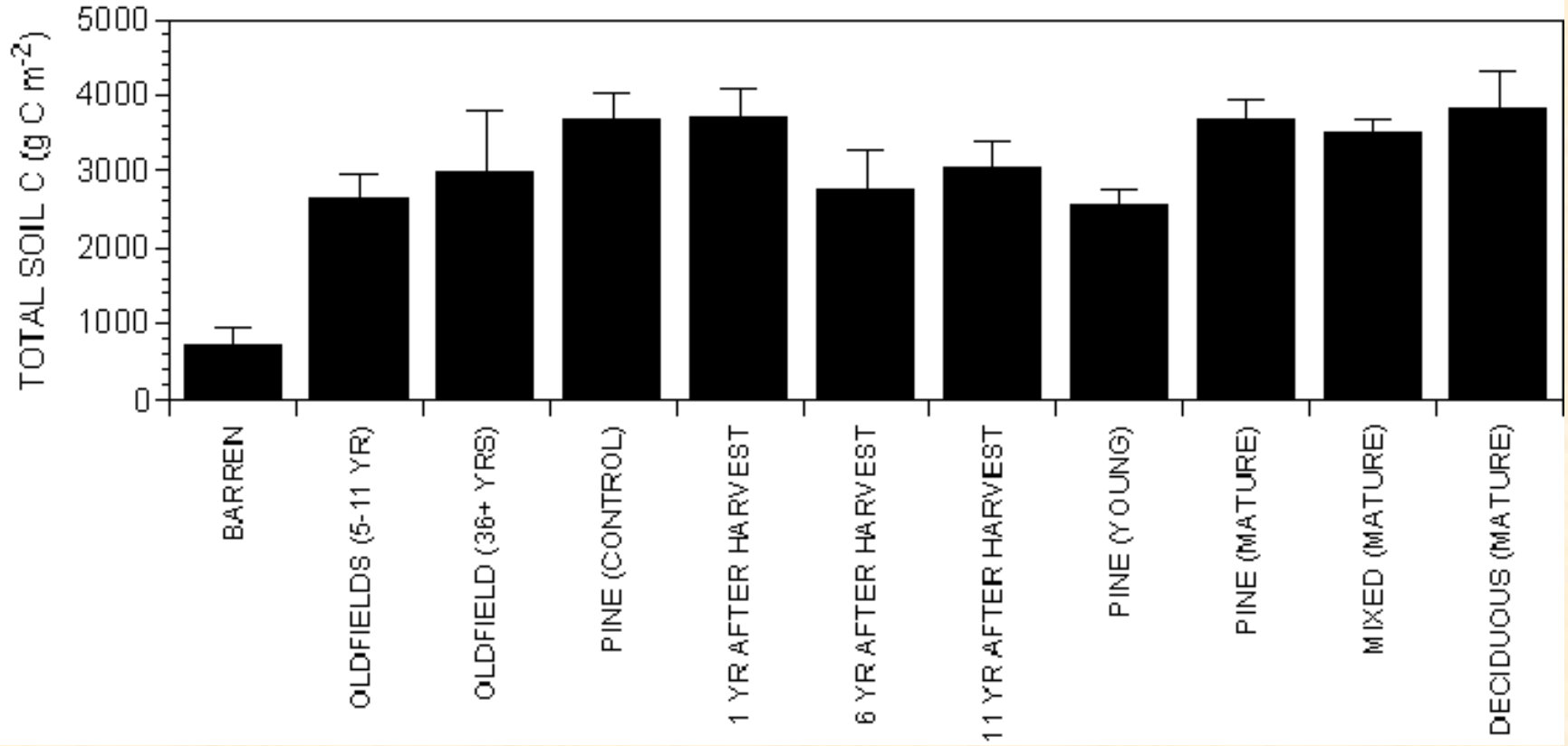
- Submodels
  - Biomass dynamics
  - Litter production
  - Plant N demand
  - Soil C and N Dynamics
  - Potential excess soil N
- Critical Variables
  - Soil N mineralization rate
  - Soil C:N ratio
  - Soil C turnover time
  - Maximum N_2-fixation
  - Internal N translocation
- Critical Relationship
  - N_2-fixation vs. relative tree biomass



Stella® Model: Applications

- Focused simulations on scenarios relevant to land management
  - Steady-state forest cover
  - Recovery of forest cover on barren soils
  - Recovery of forest cover on barren soils followed by harvest cycles
  - Conversion of forest cover to permanent old field (herbaceous) cover
  - Steady-state forest cover with variable burn cycle
  - Recovery of forest cover from barren soils with variable burn cycle
- Variables relevant to land management practices
  - Desired future condition (defined by aboveground biomass)
  - Harvest or forest disturbance interval
  - Controlled burn cycle

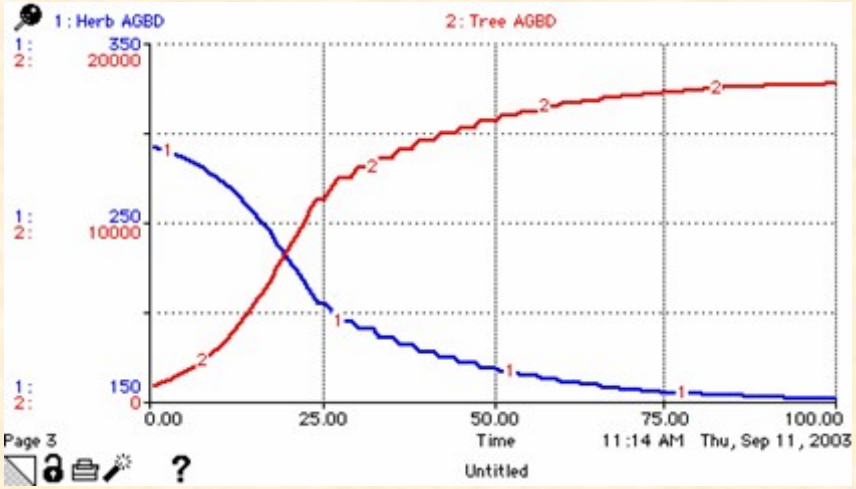
Stella® Model: Chronosequence Calibration

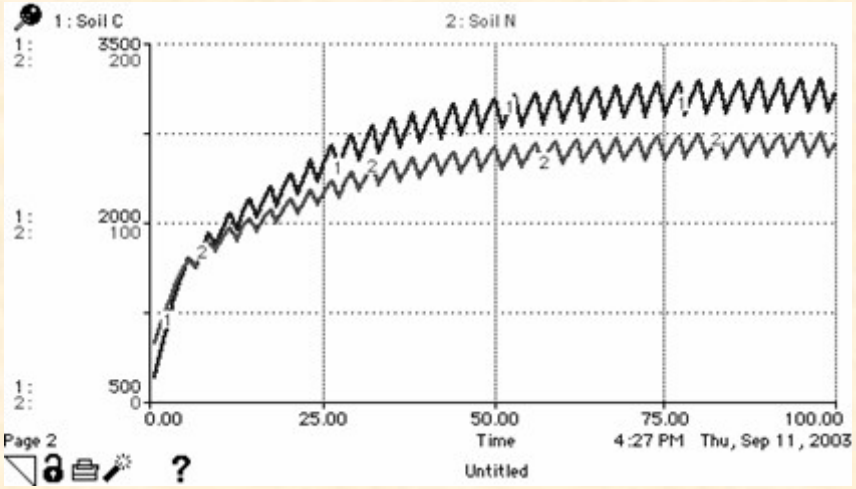


- Field data were used to build a chronosequence of recovery, disturbance, recovery
- Chronosequence data were used as calibration points during model development

Stella® Model: Recovery Simulations

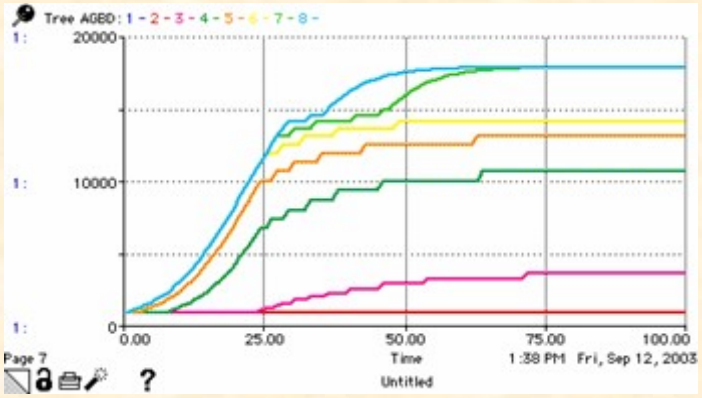
- Predicted recovery of forest cover on less sandy soils
  - Initial soil quality is 700 g C m^{-2}
  - 3-year burn cycle
  - Maximum annual N_2-fixation is 7 g N m^{-2} (coincides with fire)
- Predicted effects of fire are:
  - Decreased soil C and N stocks (an inverse relationship with burn frequency)
  - Recurring stimulation of N_2-fixation
  - Recurring pulses in potential excess soil N
- If maximum annual N_2-fixation is <2.5 g N m^{-2}, no recovery occurs

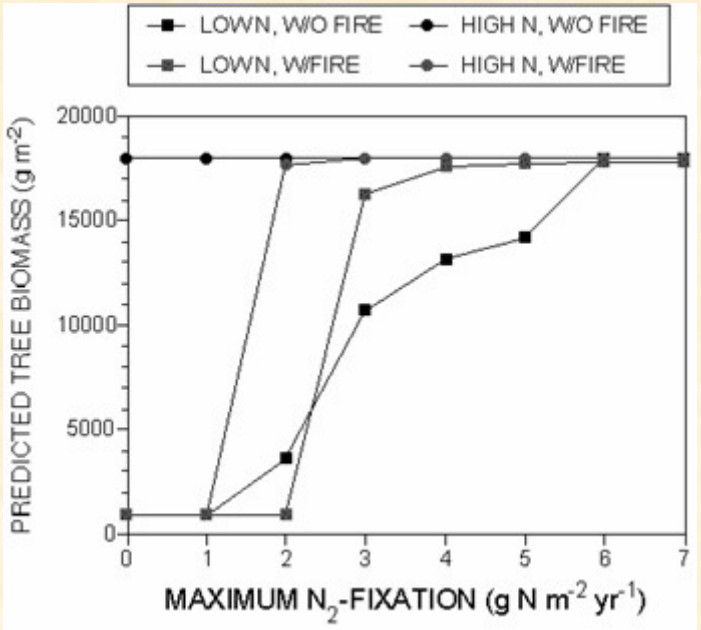




Stella® Model: Threshold for N_2-Fixation?

- N_2-fixation can limit predicted forest recovery
- Upper panel shows predicted recovery of tree biomass on less sandy soils when maximum N_2-fixation varies from 0 to 7 g N m^{-2} yr^{-1}
- Simulations indicate the development of thresholds to forest recovery at sites with:
  - High soil N availability (more sandy soils) and recurring fire (3 year cycle)
  - Low soil N availability (less sandy soils) and recurring fire (3 year cycle)
- Predicted recovery in the absence of fire does not exhibit a threshold response to N_2-fixation
- Hypothesis: interactions between fire and soil texture (N availability) may produce N_2-fixation thresholds to forest recovery on barren sites





Stella® Model: What Are We Learning?

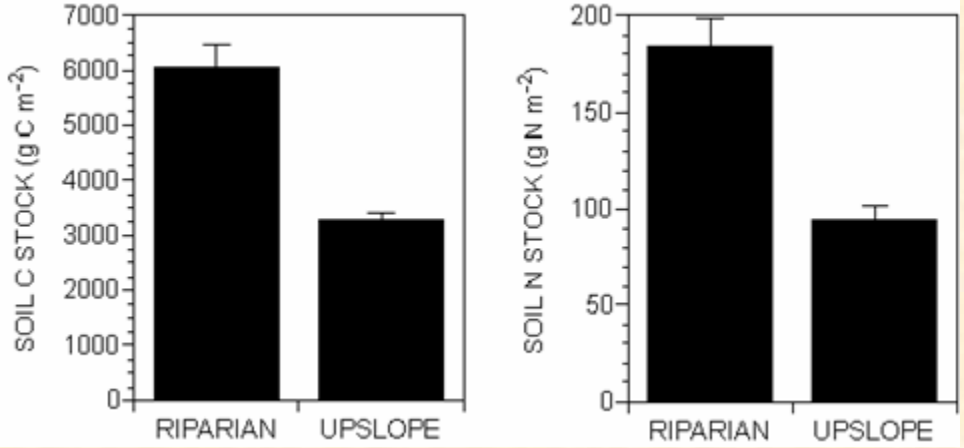
- Sensitivity analysis of model parameters (in order of increasing importance): soil C turnover, parameters related to root turnover, maximum N_2-fixation, within tree N translocation, net soil N mineralization rate, and tissue N concentrations
- Increasing the frequency of fire reduces predicted soil C and N stocks
- At sites with low soil N availability, the model predicts more frequent burning promotes forest recovery by stimulating N_2-fixation
- If N_2-fixation is small, burning reduces the rate of forest recovery
- Interactions between fire, N_2-fixation, and soil N availability (net soil N mineralization) can give rise to complex predicted patterns of forest recovery
- Continuing experimentation with the Stella® model at this stage is raising more questions than it is answering -- research needs

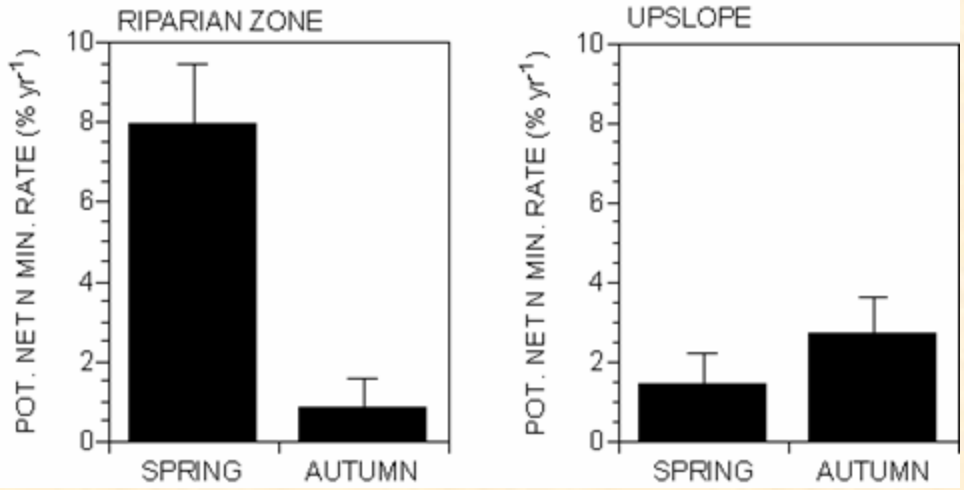
K11 Experiment: Objective & Approach

- Objective is to determine effects of fire + heavy vehicle disturbance on forms and stocks of soil C and N, and soil N transformations
- Pre-disturbance soil sampling
  - spring & fall of 2001
- Post-disturbance soil sampling (June 2003)
- Study coordinated with ORNL Team 1
- Laboratory measurements in progress:
  - Soil C (amounts and forms of soil C)
  - Soil N concentrations and stocks
  - Soil N availability (potential net soil N mineralization in aerobic laboratory incubations)

K11 Experiment: Pre-disturbance Sampling

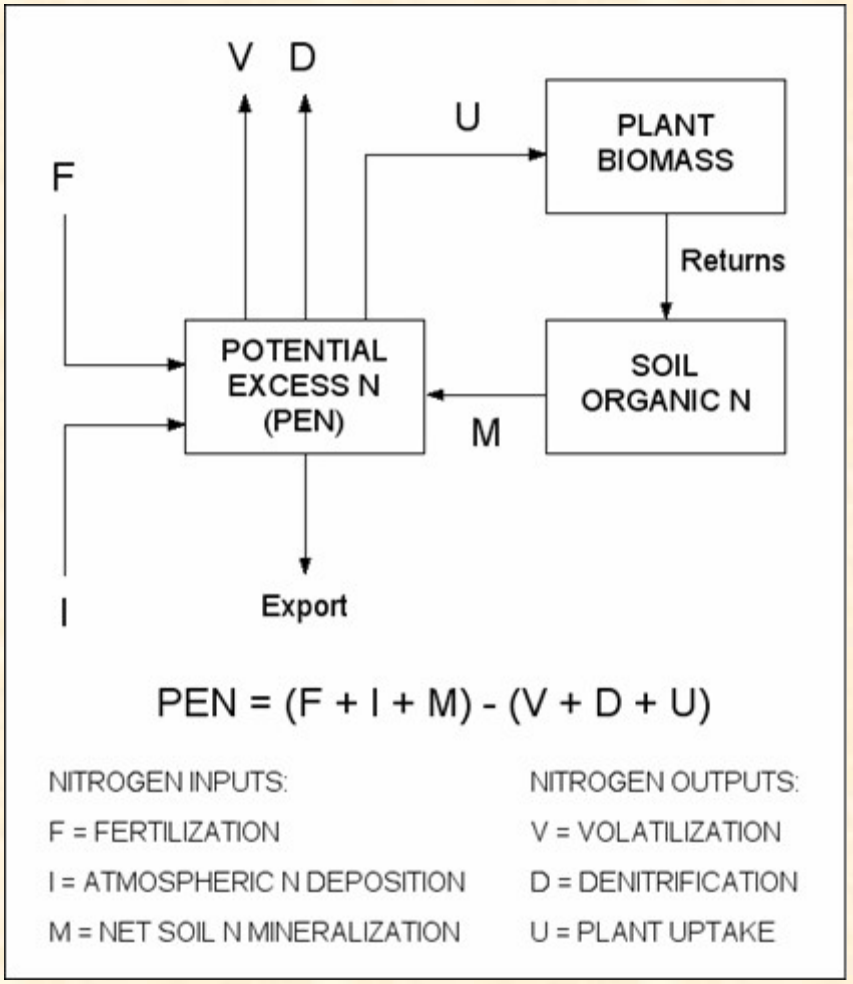
- Soil C and N stocks are greater in the near stream environment than in the upland environment at K11
- No seasonal differences for:
  - Soil C stocks
  - O-horizon C and N stocks
  - Extractable ammonium-N
  - Extractable nitrate-N
  - Net nitrification
- K11 soils are “more sandy”
  - Riparian 77.2 ± 2.4% sand
  - Upslope 84.1 ± 0.8% sand
- Potential net soil N mineralization is high in the near stream environment during spring; otherwise it is low (≈2% yr^{-1})





Spatial Analysis: Concept

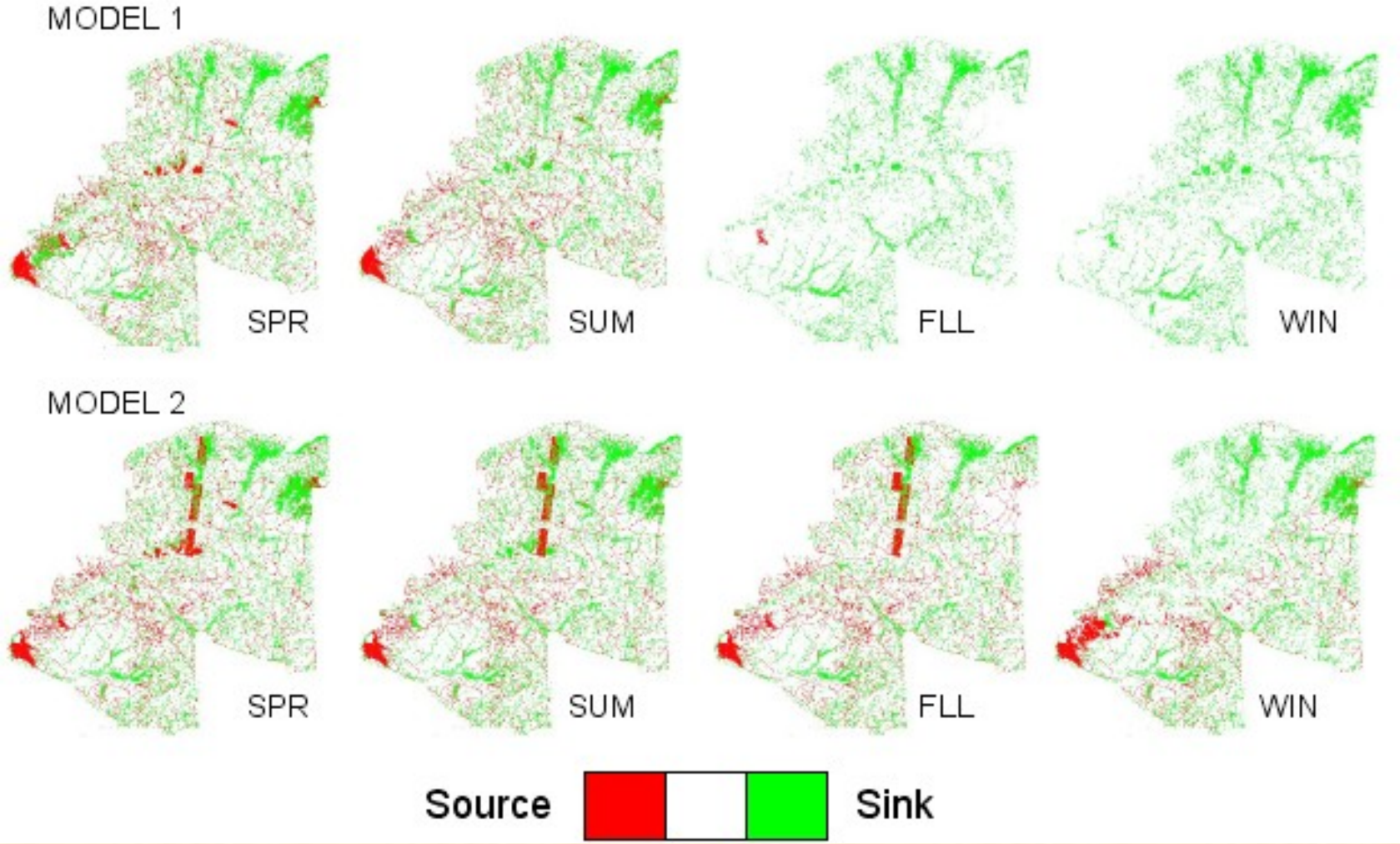
- Mass balance model for soil N
- Model partitions soil N into organically bound N and potential excess soil N (inorganic soil N)
- Fertilization - based on acres planted and fertilizer use for each crop
- Deposition - NADP/NTN
- N mineralization - soil N map (Hargrove and Post, 1998) is used in combination with net soil N mineralization rates (yr^{-1})
- Volatilization - depends on chemical form of fertilizer
- Denitrification - based on land cover
- Plant uptake - based on land cover



Spatial Analysis: Approach

- Garten, C.T., Jr., and T.L. Ashwood. 2003. A landscape level analysis of potential excess nitrogen in east-central North Carolina, USA. Water, Air, and Soil Pollution 146: 3-21.
- Steps in the GIS approach (R. Washington-Allen)
  - Land cover classified by Georgia Gap Analysis Program (1998)
  - Parameterize fluxes in the model based on land cover types
  - Partition annual fluxes into seasonal fluxes (based on seasonal factors)
  - Calculate total mass of potential excess N (i.e., N available for transport)
  - Overland flow delivery process (conservative approach)
  - Flow accumulation - drain network delineation - flow path based on DEM (Levine et al. 1993, Emani 1998)
  - Calculate total mass of N delivered to stream on seasonal and annual basis

Potential Excess N: Model Comparisons



Project Closeout: 28 Feb 2004

- Progress report to TAC - Oct. 2003
- Submit photos of 129 study sites to SEMP Data Repository
- Complete experimentation and testing of Stella® Model - Nov. 2003
- Present poster at Partners in Environmental Technology Symposium and Workshop (SERDP/ESTCP) - Dec. 2003
- Annual report for 2003
- Complete preliminary spatial analysis of soil C, N, and PEN - Jan. 2003
- Final report to TAC - Spring 2004
- Continue working on manuscripts (1 submitted and 2 in preparation)

Research Needs

- Site-specific information is lacking on attributes and processes in the N cycle that are important to predictions of potential excess N and soil nutrient thresholds
  - Plant tissue N concentrations
  - Nitrogen use efficiency
  - Seasonal N translocation within plants
  - Seasonal *in-situ* measurements of net soil N mineralization
  - Asymbiotic and symbiotic N_2-fixation
- Incorporation of site-specific data into the ORNL nutrient threshold model for ecosystem recovery/sustainability

ESD's Continuous Flow IRMS for Stable N and C Isotopes

Supplementary Slides

Research Funding

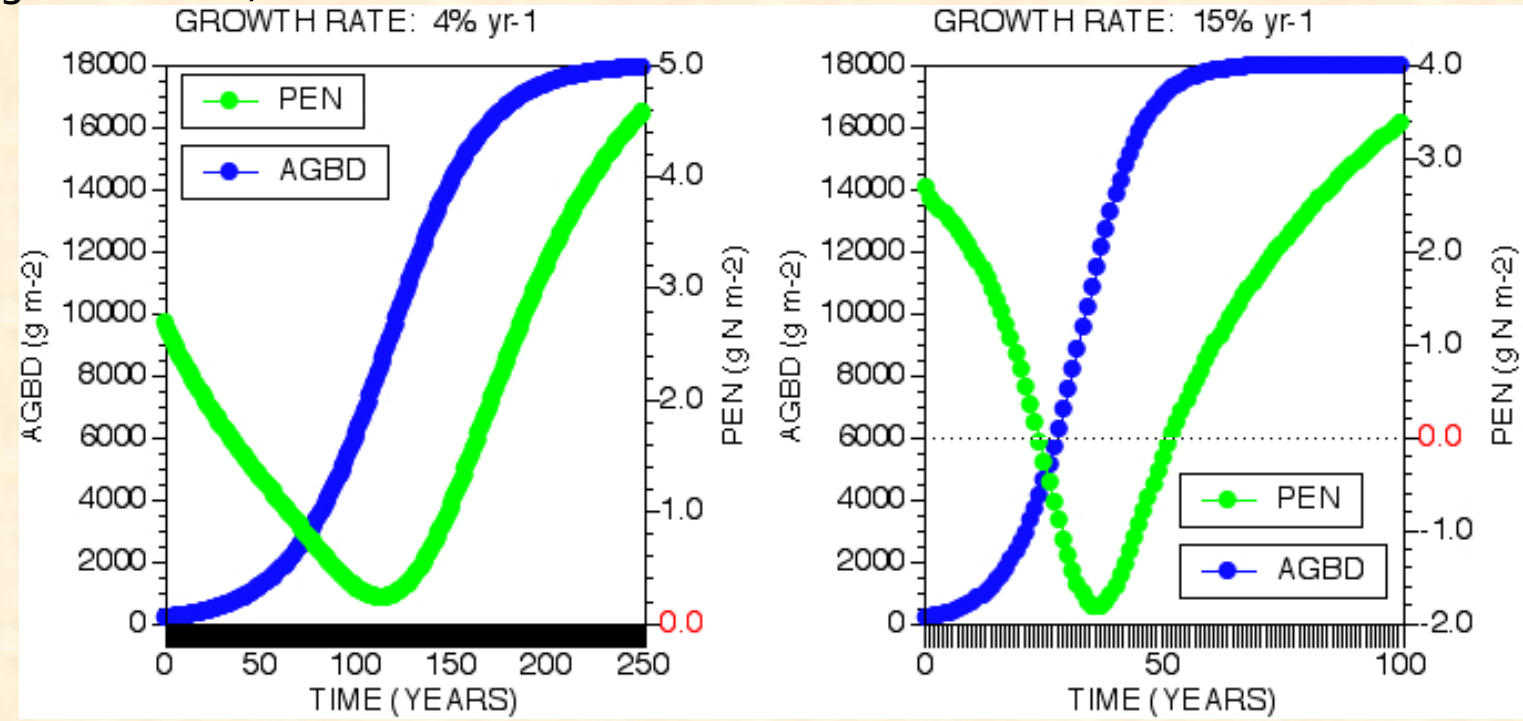
	SEMP $K	Approx. FTEs	Staff
Year 1	200	1	3+
Year 2	290	1.5	3+
Year 3	195	1	3+
Year 4	195	1	3+
Total	880		

Progress Plan

ACTIVITY	FY 00				FY 01				FY 02				FY 03			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
1. Field studies: military disturbance gradients (soil samples provided by Virginia Dale)	■	■	■	■	■	■										
2. Field studies: land cover differences (based on FB LCTA plots)		■	■	■	■	■	■	■	■	■	■					
3. Field studies: disturbance gradients, forest clear-cutting, site recovery (NRCS)							■	■	■	■	■	■	■	■		
4. Field studies: K11 (pre-treatment and post-treatment soil sampling at select locations)							■	■	■	■	■	■	■	■		
5. Field studies: longleaf pine chronosequence (to provide data for threshold modelling)											■	■	■	■		
6. Modelling: parameterize models of soil C and N for calculating thresholds to soil quality									■	■	■	■	■	■	■	■
7. Modelling: landscape level assessment of potential excess N (GIS + field data + modelling)													■	■	■	■

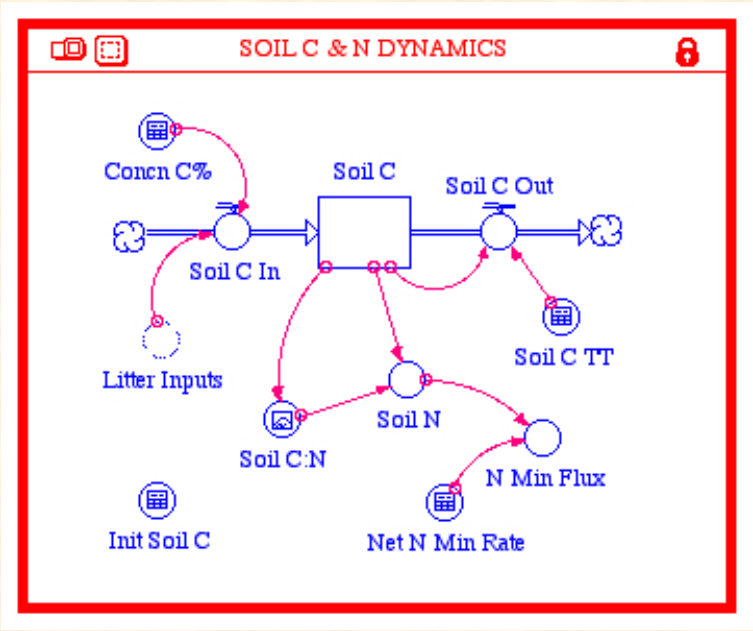
Spreadsheet Model Output

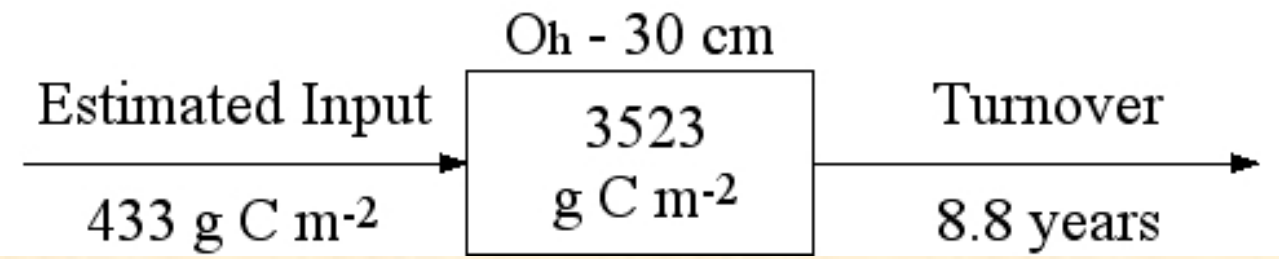
- Time to forest recovery from a barren site at different growth rates
- PEN = potential excess N and AGBD = aboveground biomass density
- Thresholds to recovery depend on (1) the desired future condition (target for biomass), (2) initial soil quality (g C m^{-2}), and (3) specified recovery rate (growth rate)



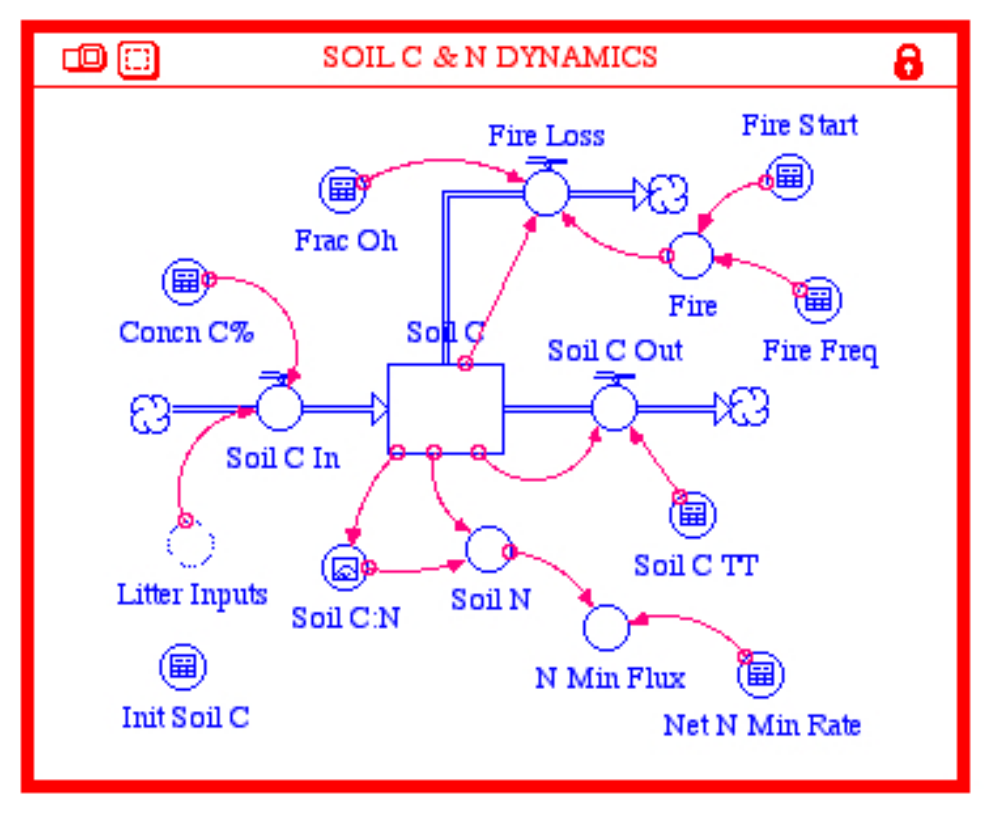
Soil Carbon Turnover

- Soil C turnover times are important to modeling thresholds associated with soil N availability
- Earlier versions of the Stella® model included two soil compartments but involved many assumptions
- Latest model includes one compartment for soil C stocks but fewer assumptions
- Estimated soil C inputs based on data obtained in mature longleaf pine stands
- Soil C turnover (approximately 9 years) was calculated from 4 oldest sites





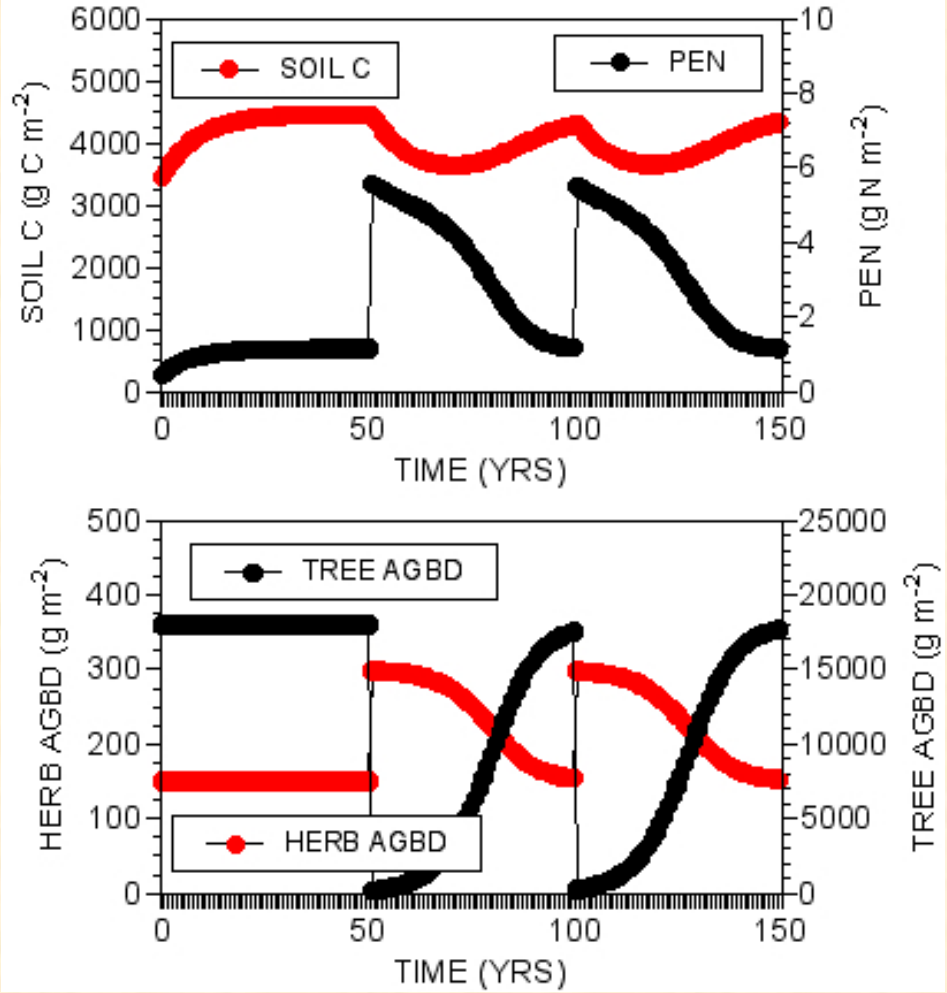
Stella® Model: Soil C and N Dynamics



- Soil C inputs are calculated based on litter mass and C concentration
- Soil C outputs represent decomposition losses and are calculated based on an estimated turnover time
- Fire loss removes soil C in the O-horizon at a specified fire frequency interval
- Soil N stocks are calculated based on soil C:N ratios
- Net soil N mineralization is based on an annual rate and the measured soil N stock

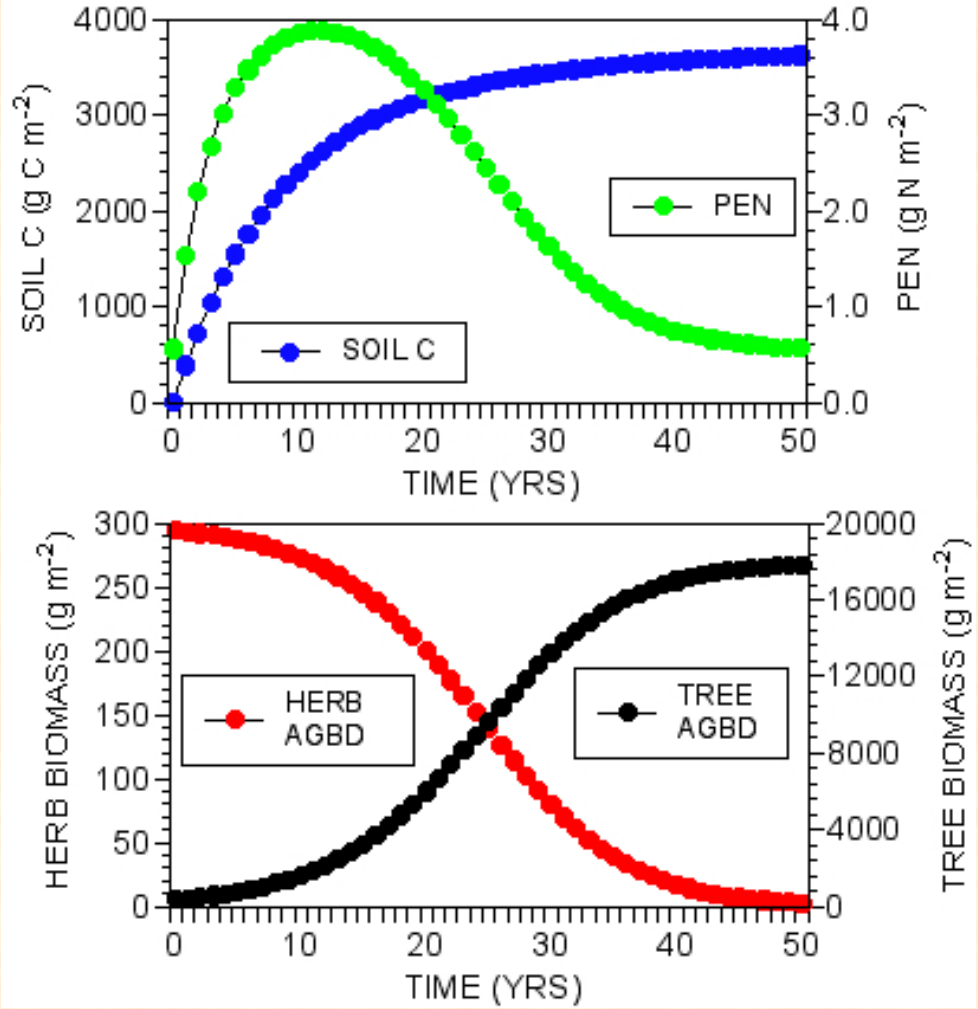
Scenario: Forest Management

- 50 year harvest interval
- Growth of herbaceous vegetation (HERB AGBD) is released by forest (TREE AGBD) removal
- Soil carbon stocks exhibit a temporary decline and then recover after forest harvesting
- Soil N availability (PEN) increases after forest harvest (less N demand)
- Model predicts that the system is sustainable
- System response depends on forest tree growth function

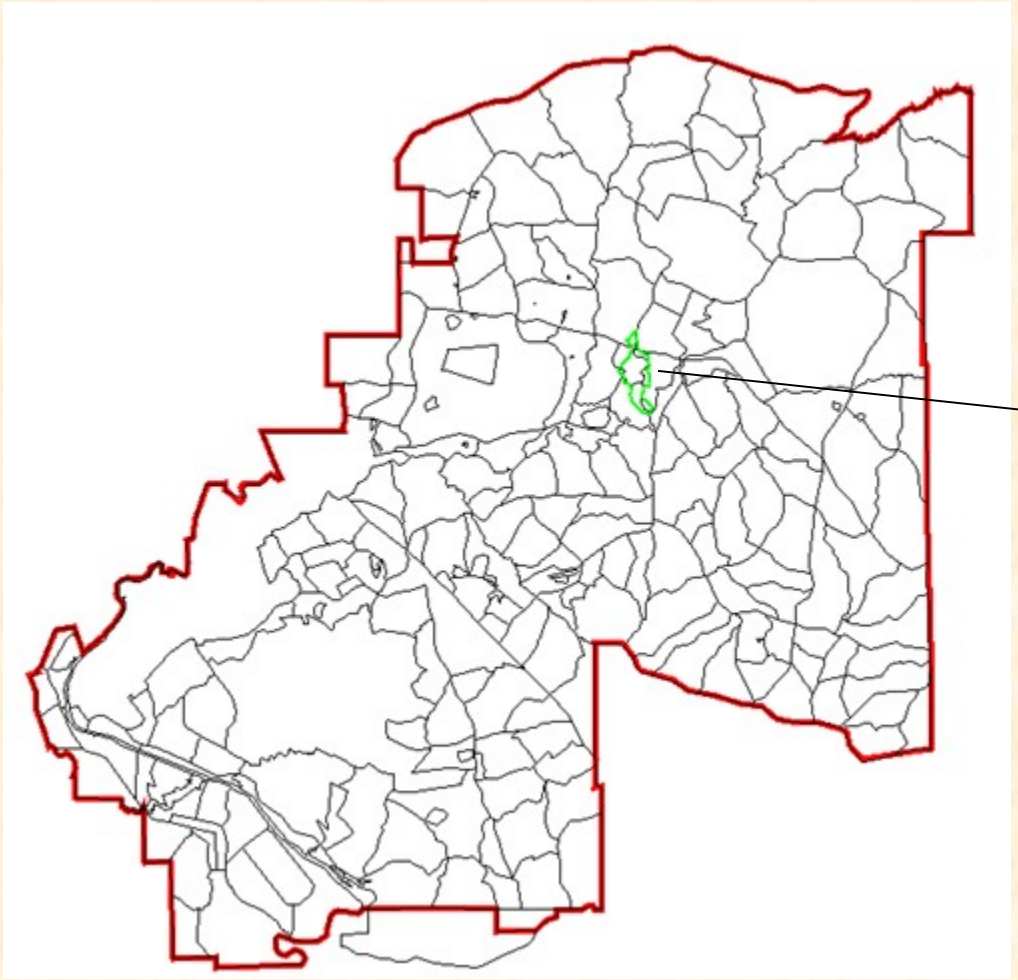


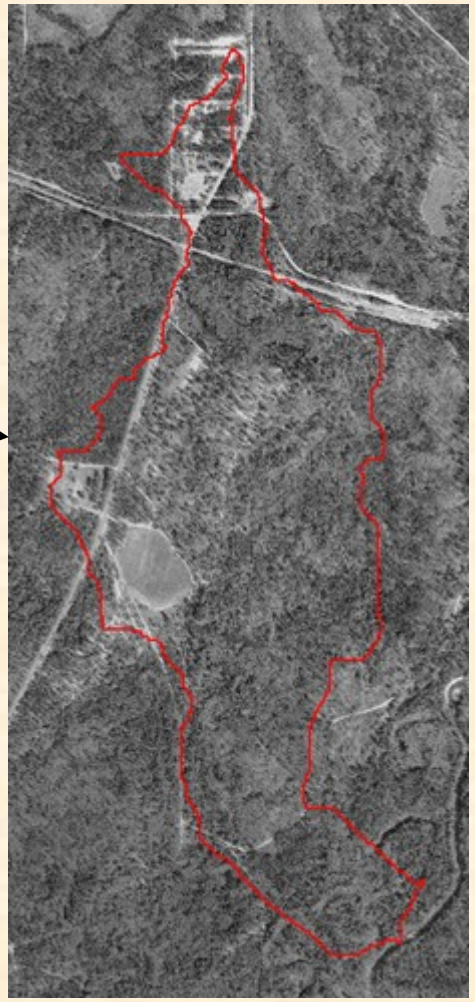
Scenario: Forest Recovery

- 50 year simulation
- Initial soil C stock was set to 0 g C m^{-2}
- Herb biomass (HERB AGBD) declined as tree biomass (TREE AGBD) increased
- Soil carbon (SOIL C) increased and available soil N (PEN) declined with forest recovery
- Thresholds to recovery were influenced primarily by rates of net soil N mineralization

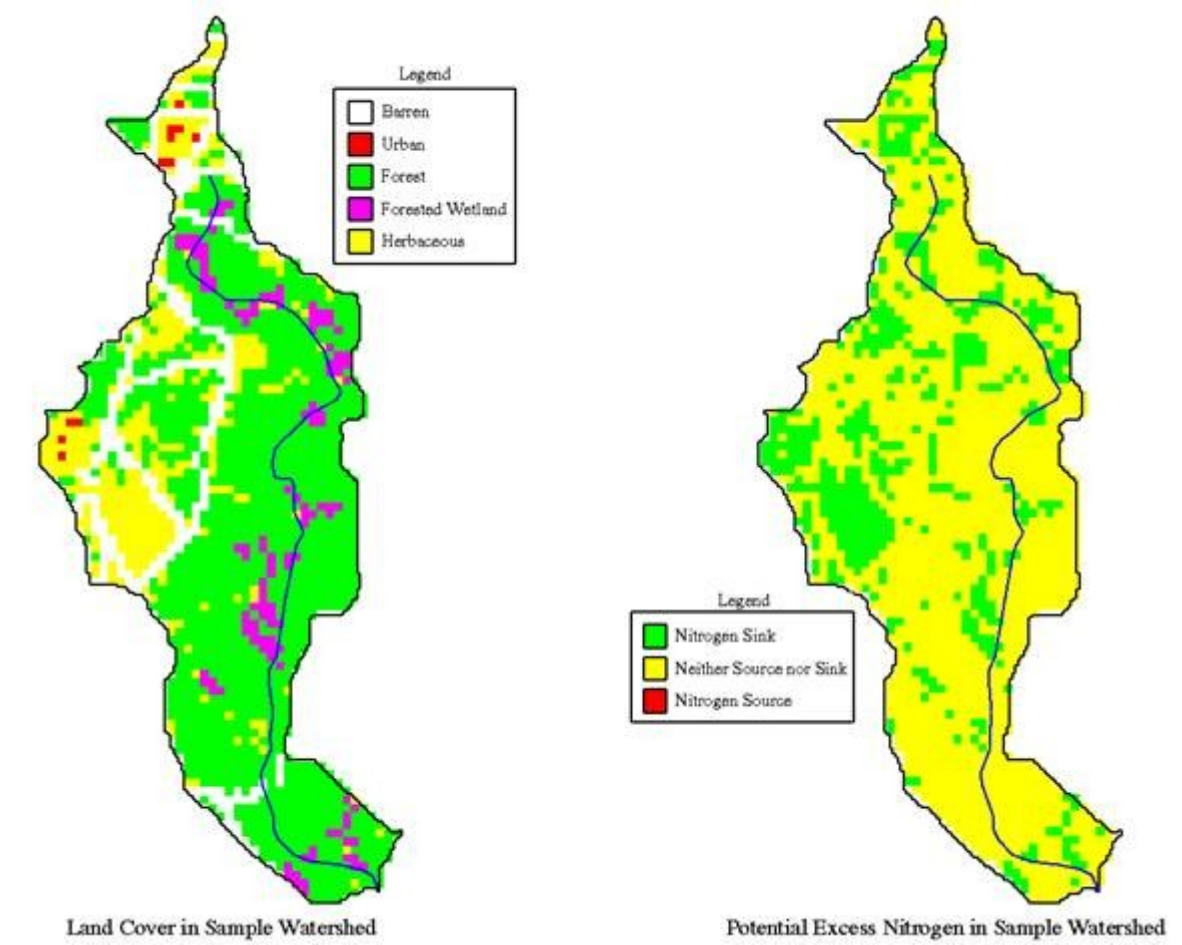


Test Watershed for Landscape Model





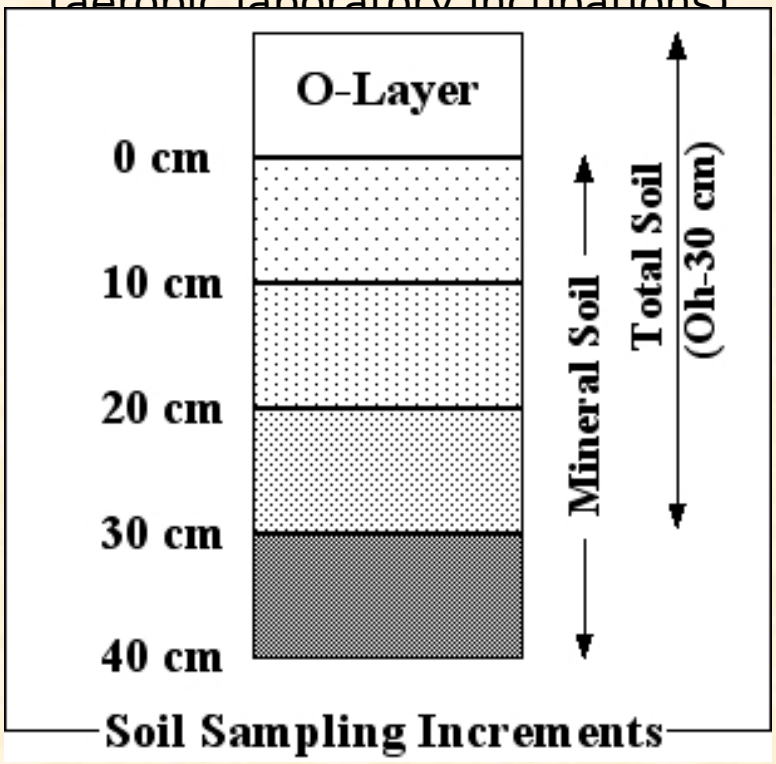
Preliminary Predictions of PEN

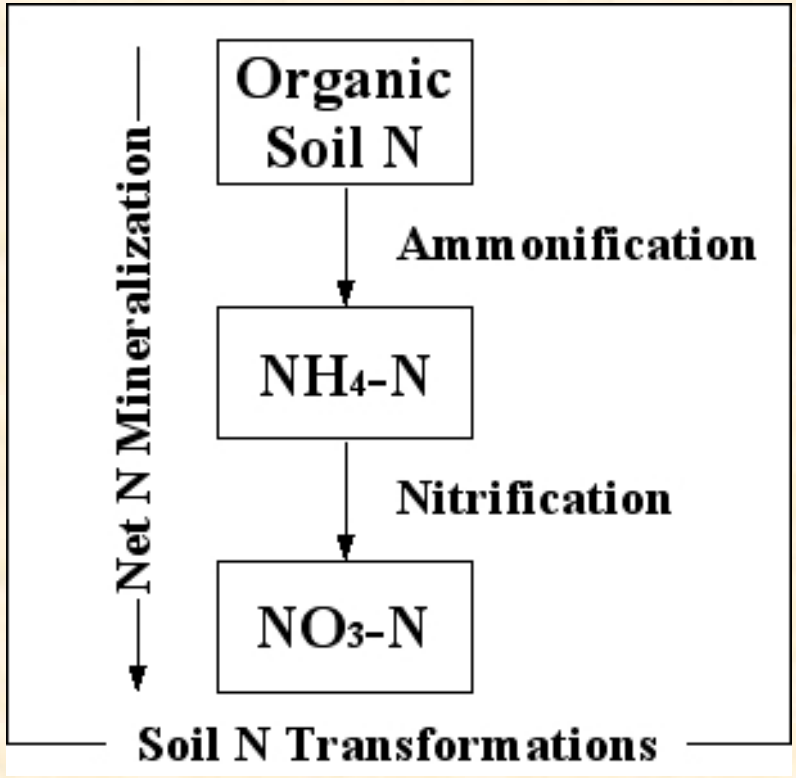


- Preliminary data do not include site specific data for Fort Benning
- Potential excess N is both a continuous (g N m^{-2}) and a categorical variable (sink, source, and borderline)
- Model predictions can generate interesting questions and identify potential new areas for research

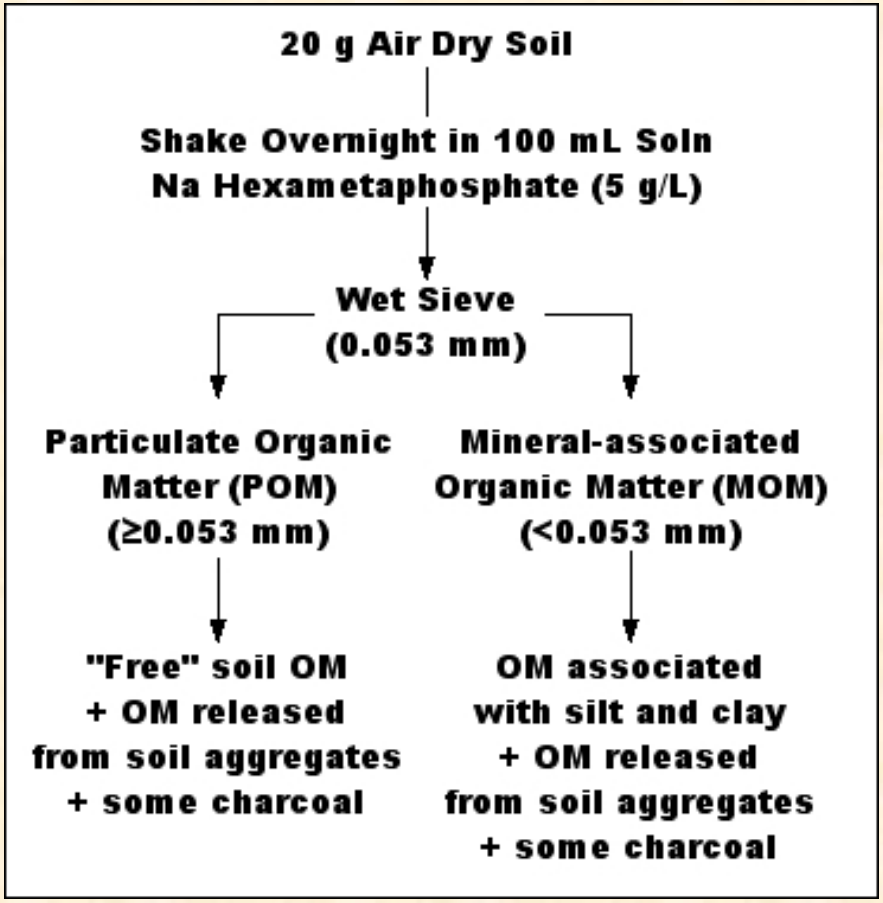
Measurements and Methods

- Profiles of soil C and N concentrations (%) and stocks (g m^{-2}) to a 40 cm soil depth
- Extractable inorganic soil N and potential net soil N mineralization rates (aerobic laboratory incubations)





Partitioning of Soil Carbon Stocks


20 g Air Dry Soil
Shake Overnight in 100 mL Soln
Na Hexametaphosphate (5 g/L)
Wet Sieve
(0.053 mm)
Particulate Organic Matter (POM) (≥0.053 mm)
Mineral-associated Organic Matter (MOM) (<0.053 mm)
"Free" soil OM + OM released from soil aggregates + some charcoal
OM associated with silt and clay + OM released from soil aggregates + some charcoal

- POM-C is a labile pool consisting of free organic matter and larger organic debris released after dispersion of soil aggregates (short turnover time is temperature dependent)
- MOM-C is a more stable pool of soil C associated with silt and clay (humics) and includes smaller organic debris released after dispersion of soil aggregates (longer turnover time)

K11 Pretreatment Sampling

Landscape position	n	Oi to 30 cm (g C m^{-2})	Oi to 30 cm (g N m^{-2})	Initial extractable soil N (µg N g^{-1})	Net N min. rate (yr^{-1})	Nitrate-N production in 12 wks (µg N g^{-1})
Near Stream	15	6064 (0.25)	184 (0.30)	4.2 (0.49)	0.09 (0.53)	9.9 (1.24)
Upland	18	3227 (0.18)	94 (0.33)	1.4 (0.45)	0.02 (1.57)	1.4 (1.21)

- Soil C and N stocks, and soil N availability is greater in the near stream environment than in the upland environment at K11 (pretreatment sampling)
- Assuming an annual litterfall of 408 g m^{-2} (Sharpe et al., 1980), the estimated annual soil C input is 367 g C m^{-2} and the estimated turnover time for soil C is 8.8 and 16.5 years, respectively, for upland and near stream sites